

## VI.10 Carbon-based Fuel Cell

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### Objectives

- Determine the technical feasibility of using coal as fuel for solid oxide fuel cells (SOFCs).

### Approach

- Develop an anode catalyst to promote the electrochemical oxidation of coal.
- Use a cold-pressing technique to fabricate the electrolyte thin film.
- Use a screen-printing technique to attach the cathode on the electrolyte.
- Use mass spectroscopy and infrared spectroscopy to monitor the composition of the effluent from the fuel cell.

### Accomplishments

- Design and construction of a SOFC capable of producing 100 mA/cm<sup>2</sup> at 0.6 V using Ohio #5 coal as the fuel.
- Successful test of the solid oxide fuel cell for the direct oxidation of methane.
- Test of the solid oxide fuel cell using activated carbon, petroleum coke, and Ohio #5 coal as fuels.
- Successful fabrication of an intermediate-temperature SOFC using SDC [i.e., samarium-doped ceria (Sm<sub>0.2</sub>Ce<sub>0.8</sub>O<sub>1.9</sub>)] as the electrolyte and SSC [i.e., strontium-doped samarium cobaltite (Sm<sub>0.5</sub>Sr<sub>0.5</sub>CoO<sub>3</sub>)] as the cathode.
- The fuel cell using Pt as the anode, SDC as the electrolyte, and SSC as the cathode produced 100 mA/cm<sup>2</sup> at 0.4 V using H<sub>2</sub> as the fuel at 700°C, and 125 mA/cm<sup>2</sup> at 0.4 V at 800°C.

### Future Directions

- Further work is needed to improve the current density of coal-based fuel cells.

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### Introduction

The direct use of carbon from coal as a fuel for the solid oxide fuel cell to generate electricity is an innovative concept for power generation. This type of C-fuel cell (carbon-based fuel cell) could offer significant advantages in the following areas: (i) minimization of NO<sub>x</sub> emissions due to the operating temperature range of 700-1000°C, (ii) high overall efficiency because of the direct conversion of

carbon to CO<sub>2</sub>, and (iii) low investment and maintenance cost due to simplicity of the process.

The objective of this study is to determine the technical feasibility of using coal as the fuel for solid oxide fuel cells. The performance of this C-fuel cell was determined by measuring the voltage output and current density as a function of temperature, time, anode catalyst compositions, concentration of CO<sub>2</sub>, and composition of carbon black and coal. The results of this study will allow us to evaluate the

limitations and potential of the carbon-based fuel cell for practical applications.

### Approach

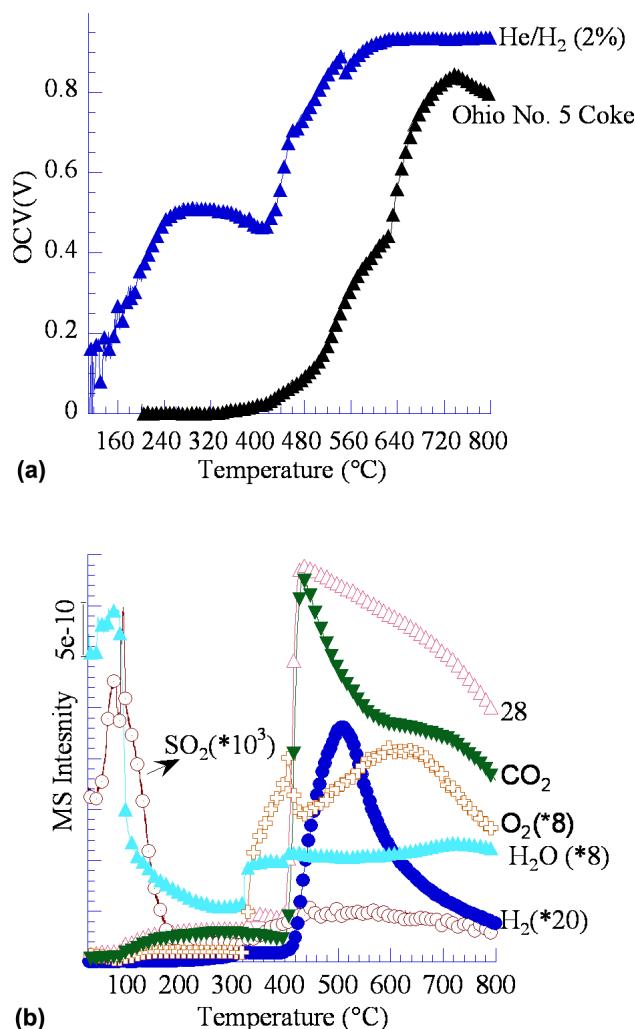
To determine the technical feasibility of using coal as the fuel to the solid oxide fuel cell, the first step is to fabricate a SOFC with an anode which can resist sulfur poisoning during the electrochemical oxidation of coal. The second step is to determine the performance of the fuel cell using coke. Due to the long residence time of coal in the high-temperature SOFC, the majority of coal is devolatilized and transformed into coke.

### Results

Figure 1(a) shows the OCV (i.e., open circuit voltage) versus temperature for a solid oxide fuel cell with a modified Ni as the anode catalyst. The OCV increased with temperature for both  $H_2$  and Ohio #5 coke. Ohio #5 coke was produced by heating Ohio #5 coal at 800°C for 20 minutes. The heating process resulted in devolatilization of coal, producing coke. The major components in the coke are carbon and inorganic compounds such as silica, Fe oxides, and various oxides of transition metals which form the fly ash after carbon is electrochemically oxidized to  $CO_2$ .

The use of  $H_2$  as a fuel produced  $H_2O$  as the only product, whereas the use of coke as the fuel produced  $CO$ ,  $CO_2$ ,  $O_2$ ,  $H_2$  and  $H_2O$ . At low temperature (30-200°C), a significant fraction of residual sulfur compounds is released in the form of  $SO_2$ , as illustrated in Figure 1 (b). Comparison of OCVs for  $H_2$  and coke shows that the modified Ni anode performed significantly better for  $H_2$  than for coke. The low performance of the fuel cell using Ohio #5 coke as the fuel could be a result of the sulfur compounds which were released in the form of  $SO_2$ .

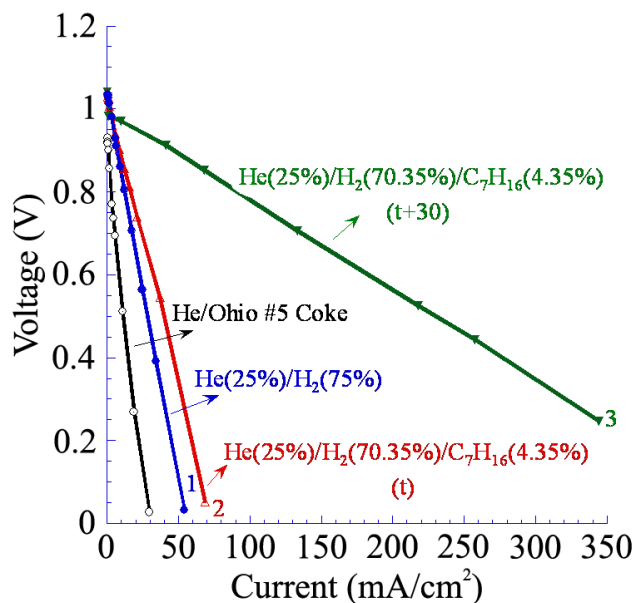
Figure 2 compares the performance of a modified Ni anode SOFC with coke,  $H_2$ , and heptane ( $C_7H_{16}$ ) as the fuels. All of the I-V (i.e., the fuel cell performance) curves show increases in current density ( $mA/cm^2$ ) with decreases in voltage. This is a result of increases in internal resistance of the fuel cell due to increases in withdrawing the electrical current from the fuel cell.



**Figure 1.** OCV (Voltage at zero current) and the Composition of the Effluent of the Anode Compartment

The fuel cell performance decreases in the following order: heptane >  $H_2$  > coke. The low current density produced from coke appears to be due to the lack of catalyst activity for the electrochemical oxidation of coke. The modified Ni catalyst used in this study gave a higher current density for  $H_2$  than for coke, reflecting its catalytic activity for  $H_2$  oxidation.

The exposure of the anode to heptane caused a significant increase in the current density. This increase could be due to build-up of carbon filaments, which increase the electrical connection among Ni sites, facilitating the transport of electrons from the reaction sites to the external circuit, thus enhancing the current density.



**Figure 2.** I-V Curves on a Modified Ni Anode Solid Oxide Fuel Cell at 800°C.

Replacement of the modified Ni catalyst with a transition metal catalyst and increasing the fuel cell temperature to 950°C resulted in an increase in the fuel cell performance to 100 mA/cm<sup>2</sup> at 0.6 V.

## **Conclusions**

The performance of the carbon-based fuel cell developed in this study showed low current density. The performance of the fuel cell could be enhanced by improving the activity of the anode and the diffusion flux of the oxygen anion across the solid electrolyte. [1]

## **Special Recognitions & Awards/Patents Issued**

1. "Carbon-based fuel cell," U.S. Provisional Application No. 60/558,856, filed April 2, 2004.

## **FY 2005 Publications/Presentations**

1. Chuang, S. S. C., "Catalysis of Solid Oxide Fuel Cells," "Catalysis-a Specialist Periodical Report." Ed. J. J. Spivey, The Royal Society of Chemistry, Vol. 18, 2005. pp 186-198. Cambridge, U.K.

## **References**

1. Chuang, S. S. C., "Catalysis of Solid Oxide Fuel Cells," "Catalysis-a Specialist Periodical Report." Ed. J. J. Spivey, The Royal Society of Chemistry, Vol. 18, 2005. pp 186-198. Cambridge, U.K.